

# Prospects for Future Kaon Physics at Fermilab

Presentation to the  
Fermilab  
Physics Advisory Committee

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March 28<sup>th</sup> , 2008



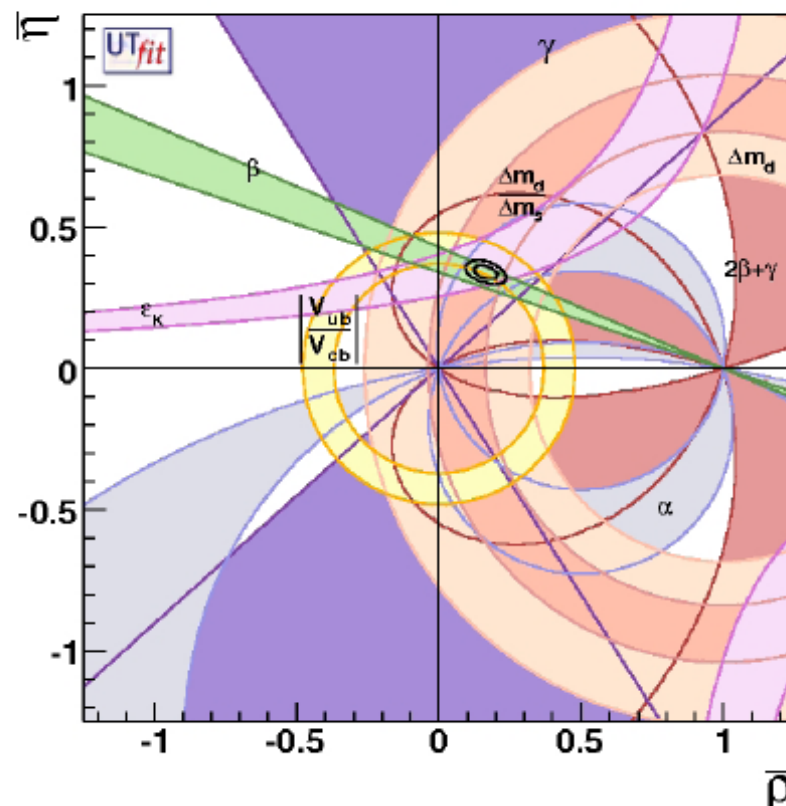
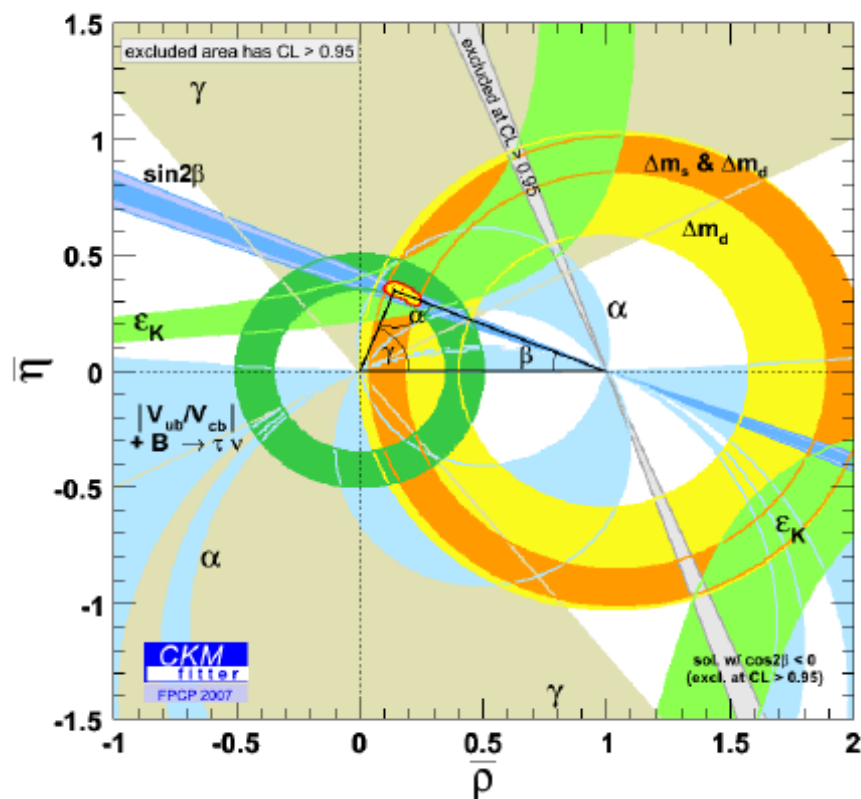
# Discussion Today

- Physics case.
- Project-X Workshops: Nov 2007, Jan 2008.  
200-person mailing list of interested parties, about 50 people actively participated workshops.
- New experimental ideas that emerged at the workshops.
- Next steps.

## The main lessons of flavour physics:

### I. The SM is very successful in describing quark-flavour mixing

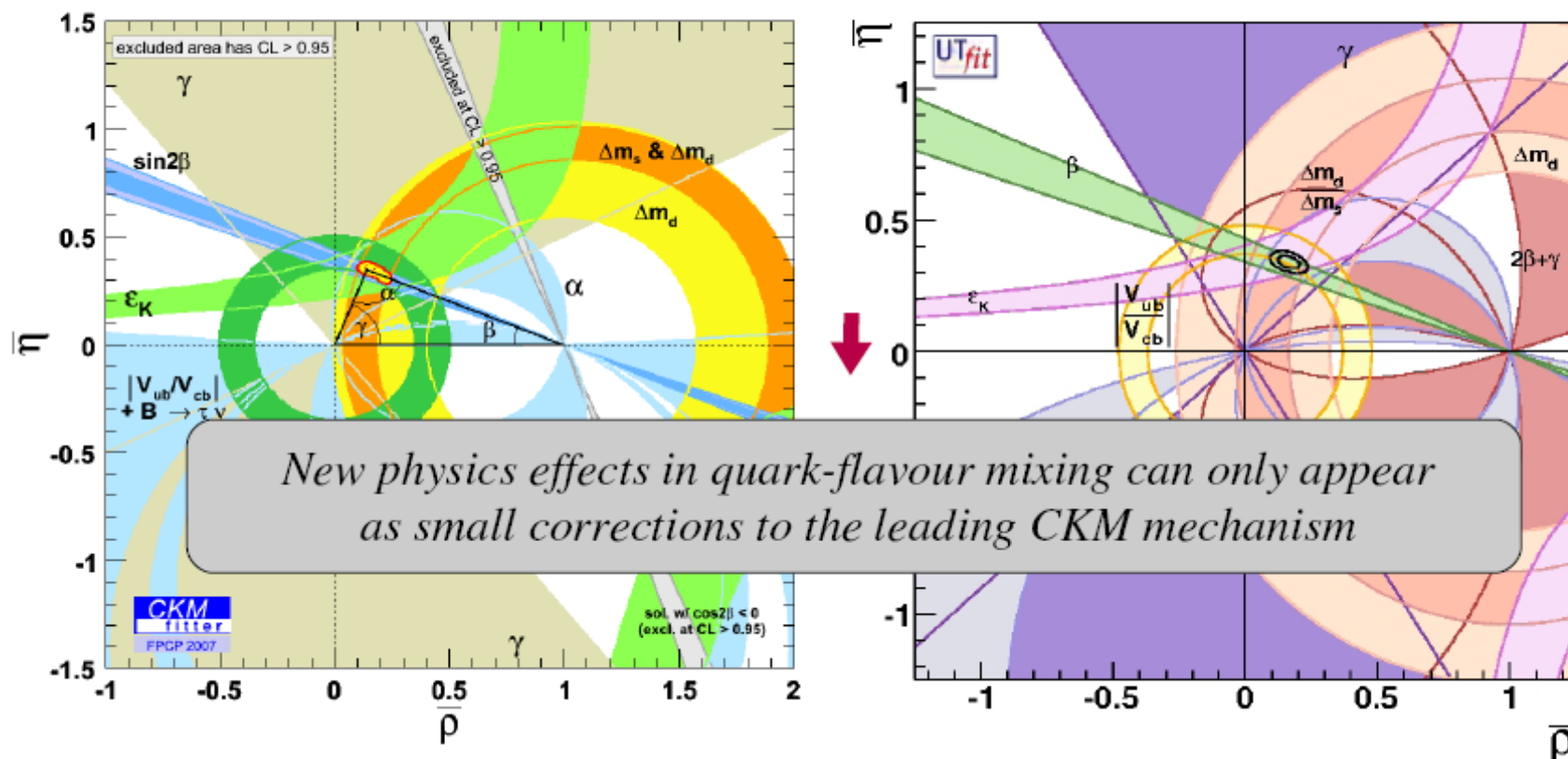
This is quite clear looking at the consistency of the various constraints appearing in CKM fits



## The main lessons of flavour physics:

### I. The SM is very successful in describing quark-flavour mixing

This is quite clear looking at the consistency of the various constraints appearing in CKM fits, and by the absence of significant deviations from the SM in processes such as  $B \rightarrow X_s \gamma$  ( $l^+ l^-$ ),  $D$ - $\bar{D}$  mixing, rare  $K$  decays, ...



# The Data has led us to a World of Minimal Flavor Violation...

$$M(B_d - \bar{B}_d) \sim \frac{(y_t V_{tb}^* V_{td})^2}{16 \pi^2 M_W^2} + \left( c_{NP} \frac{1}{\Lambda^2} \right)$$

← contribution of the new heavy degrees of freedom

$c_{NP}$	$\nearrow$ $\rightarrow$ $\rightarrow$ $\searrow$	$\sim 1$	$\xrightarrow{\text{tree/strong + generic flavour}}$	$\Lambda \gtrsim 2 \times 10^4 \text{ TeV [K]}$
		$\sim 1/(16 \pi^2)$	$\xrightarrow{\text{loop + generic flavour}}$	$\Lambda \gtrsim 2 \times 10^3 \text{ TeV [K]}$
		$\sim (y_t V_{ti}^* V_{tj})^2$	$\xrightarrow{\text{tree/strong + MFV}}$	$\Lambda \gtrsim 5 \text{ TeV [K \& B]}$
		$\sim (y_t V_{ti}^* V_{tj})^2 / (16 \pi^2)$	$\xrightarrow{\text{loop + MFV}}$	$\Lambda \gtrsim 0.5 \text{ TeV [K \& B]}$

recent analysis:  
Bona *et al.* '07

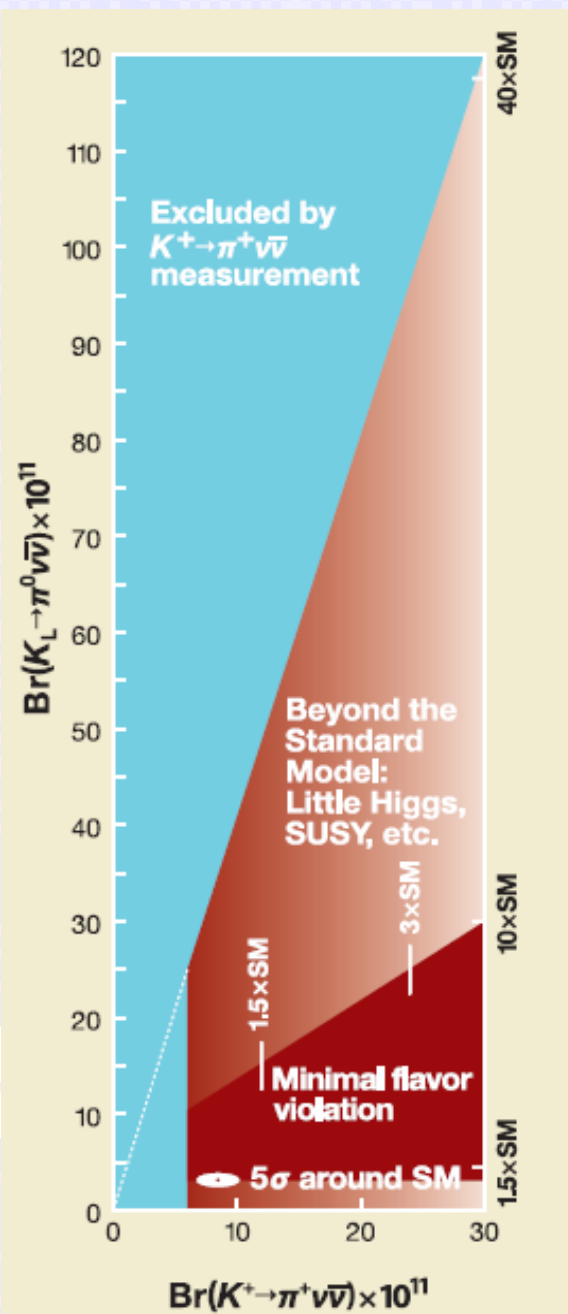
If you don't think this is an accident of  $\Delta F=2$ ...  $\Rightarrow$  MFV

G. Isidori, LP-2007

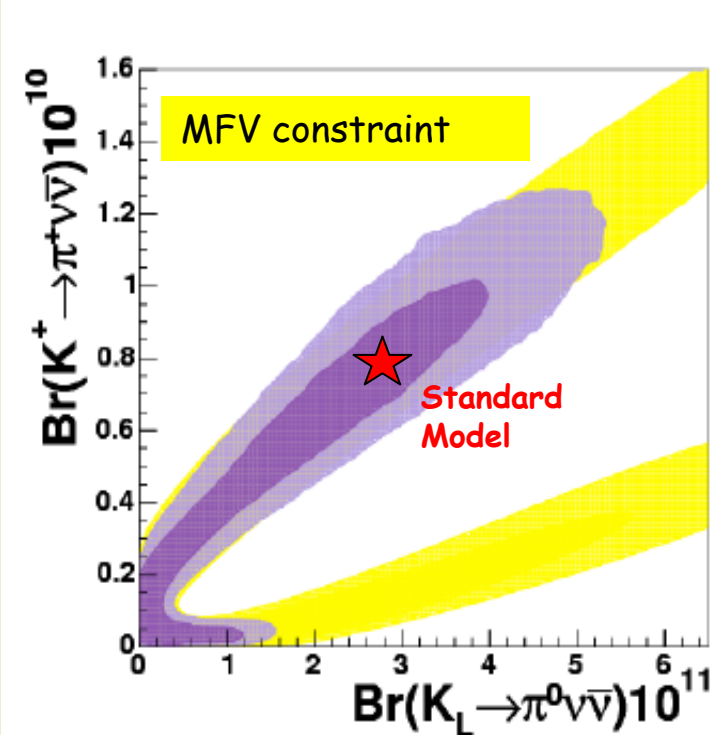
# Minimal Flavor Violation limits New Physics enhancements to less than x2. High premium on rock-solid SM predictions

Branching Ratios	MFV (95%)	SM (68%)	SM (95%)
$Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \times 10^{11}$	$< 11.9$	$8.3 \pm 1.2$	[6.1, 10.9]
$Br(K_L \rightarrow \pi^0 \nu \bar{\nu}) \times 10^{11}$	$< 4.59$	$3.08 \pm 0.56$	[2.03, 4.26]
$Br(K_L \rightarrow \mu^+ \mu^-)_{SD} \times 10^9$	$< 1.36$	$0.87 \pm 0.13$	[0.63, 1.15]
$Br(B \rightarrow X_s \nu \bar{\nu}) \times 10^5$	$< 5.17$	$3.66 \pm 0.21$	[3.25, 4.09]
$Br(B \rightarrow X_d \nu \bar{\nu}) \times 10^6$	$< 2.17$	$1.50 \pm 0.19$	[1.12, 1.91]
$Br(B_s \rightarrow \mu^+ \mu^-) \times 10^9$	$< 7.42$	$3.67 \pm 1.01$	[1.91, 5.91]
$Br(B_d \rightarrow \mu^+ \mu^-) \times 10^{10}$	$< 2.20$	$1.04 \pm 0.34$	[0.47, 1.81]

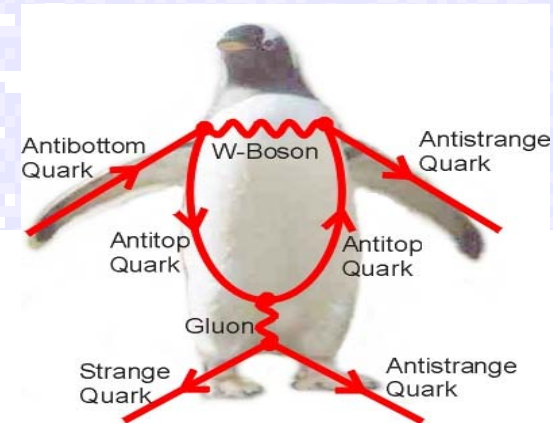
Bobeth et, al. Nucl.Phys. B726 (2005) 252-274C, hep-ph/0505110



$$K \rightarrow \pi \nu \bar{\nu}$$



C. Bobeth, M. Bona, A. Buras, T. Ewerth,  
M. Pierini, L. Silvestrini, A. Weiler, hep-ph/0505110



**Powerful probe of  
Minimum Flavor  
Violation where  
enhancements are  
less than x2-x3**

**Uniqueness:** Theoretical error <2% for neutral, <4% charged modes motivate 1000-event experiments---conceivable with Project-X!

# Project-X: A blow-torch of protons...all the time!

Per year

Facility	Duty Factor	Clock hours	Beam hours	Projected # of $K \rightarrow \pi \nu \bar{\nu}$
CERN-SPS (450 GeV)	30%	1420	405	40 (charged)
Booster Stretcher (8GeV, 16kW)	90%	5550	5000	40 (charged)
Tevatron-Stretcher (120 GeV)	90%	5550	5000	200 (charged)
ProjectX Stretcher (8GeV, 200kW)	90%	5550	5000	250 (charged)
JPARC-I (30 GeV)	21%	2780	580	~1 (neutral)
BNL AGS (24 GeV)	50%	1200	600	20 (neutral)
JPARC-II (30 GeV)	21%	2780	580	30 (neutral)
Booster Stretcher (8GeV, 16kW)	90%	5550	5000	30 (neutral)
ProjectX Stretcher (8GeV, 200kW)	90%	5550	5000	300 (neutral)

★ Moving toward full approval.

J-PARC - Neutrino:Kaon = 50%:50%

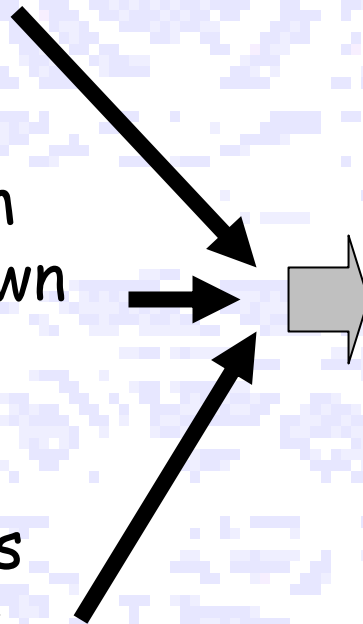
# Charged Mode, Where we are at Today

BNL program <sup>★</sup> has established the process.

The CERN NA48 program evolves **step-by-step** down the sensitivity ladder.

Next generation concepts and designs developed by R&D for the Fermilab CKM experiment.

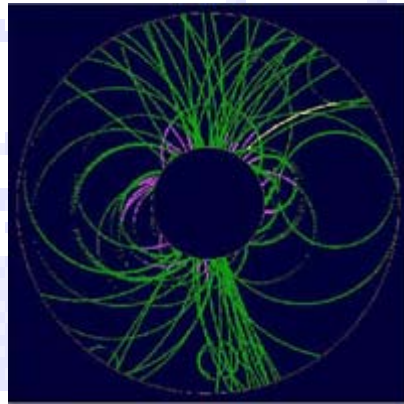
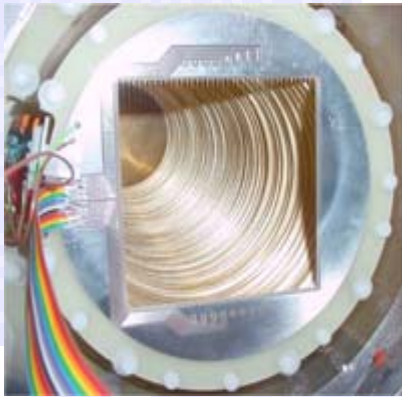
The now approved CERN NA62 experiment marches toward a 100 event measurement early next decade



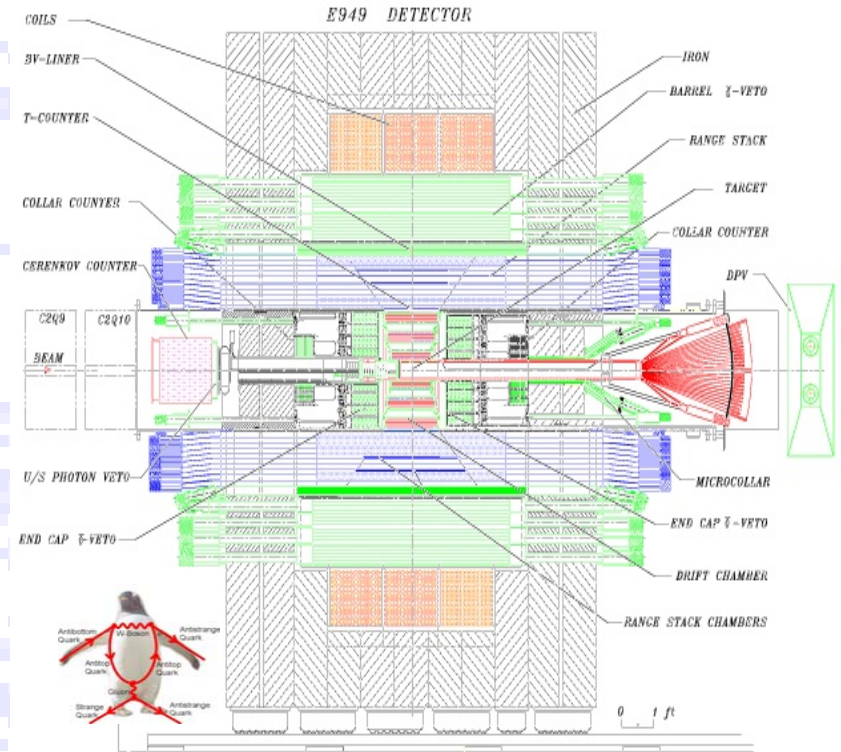
★ Measurement of the  $K^+ \rightarrow \pi^+ \nu \nu$  branching ratio. (March 2008)  
Phys.Rev.D77:052003,2008, FERMILAB-PUB-08-065-CD-E

# New Charged Mode Ideas Discussed at this Workshop

- Exploit Project-X proton intensities to develop a next-generation stopped  $K^+$  experiment built from modern detector technology. Examples include ultra-low mass ILC trackers in high ( $>3T$ ) solenoidal tracking volumes.



Ultra-low-mass TPC tracking technology developed by the LCTPC collaboration. (photos courtesy of Cornell)



BNL E787/E949 Detector

1000 events conceivable with next generation stopped expt driven by Project-X.

# Charged Mode, Where Fermilab and Project-X could go...

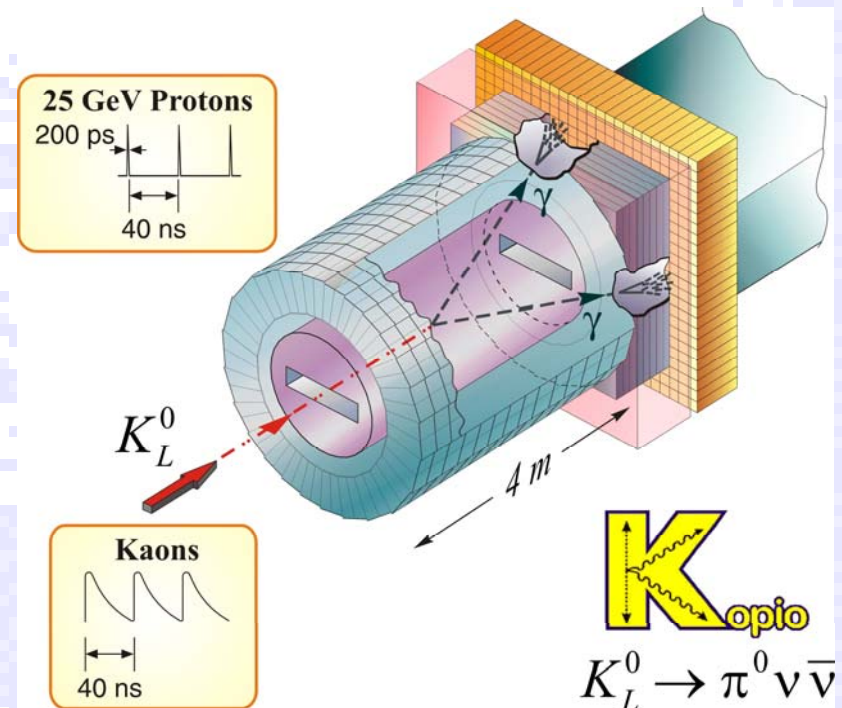
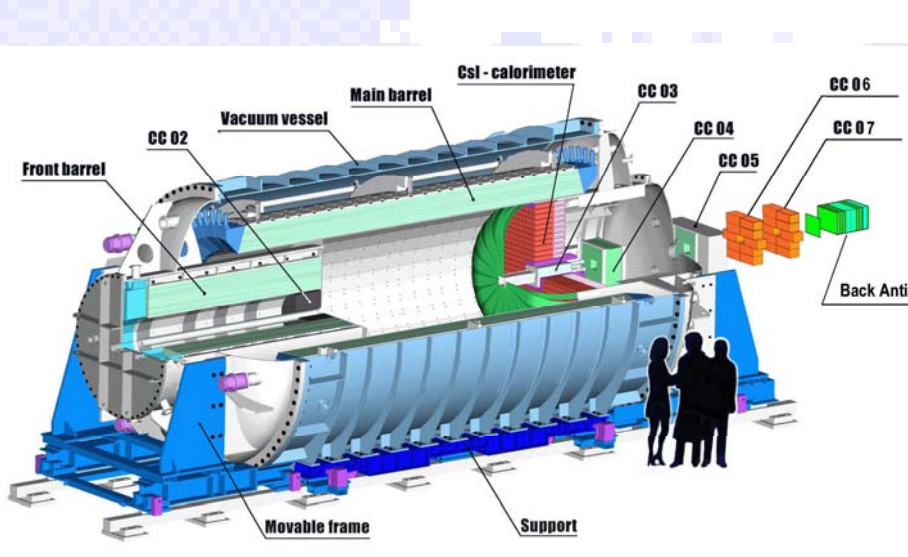
- In-flight experiment driven by the Main Injector or Tevatron: Follow-up the CERN NA62 with a high-energy separated  $K^+$  beam. 200-events/year plausible based on the NA62 and CKM designs. Does not require Project-X but would compete directly for Main Injector and/or Tevatron protons.
- Next-generation stopped kaon experiment based on the demonstrated BNL-E787 technique upgraded with modern detector technology. About 40-events/year achievable with a 20 kW 8 GeV beam, 250-events/year plausible with a 200 kW 8 GeV beam.
- Both options have an existing solid basis for design and costing, the stopped technique has a demonstrated feasibility.

# Neutral Mode: “Nothing-in, nothing out”

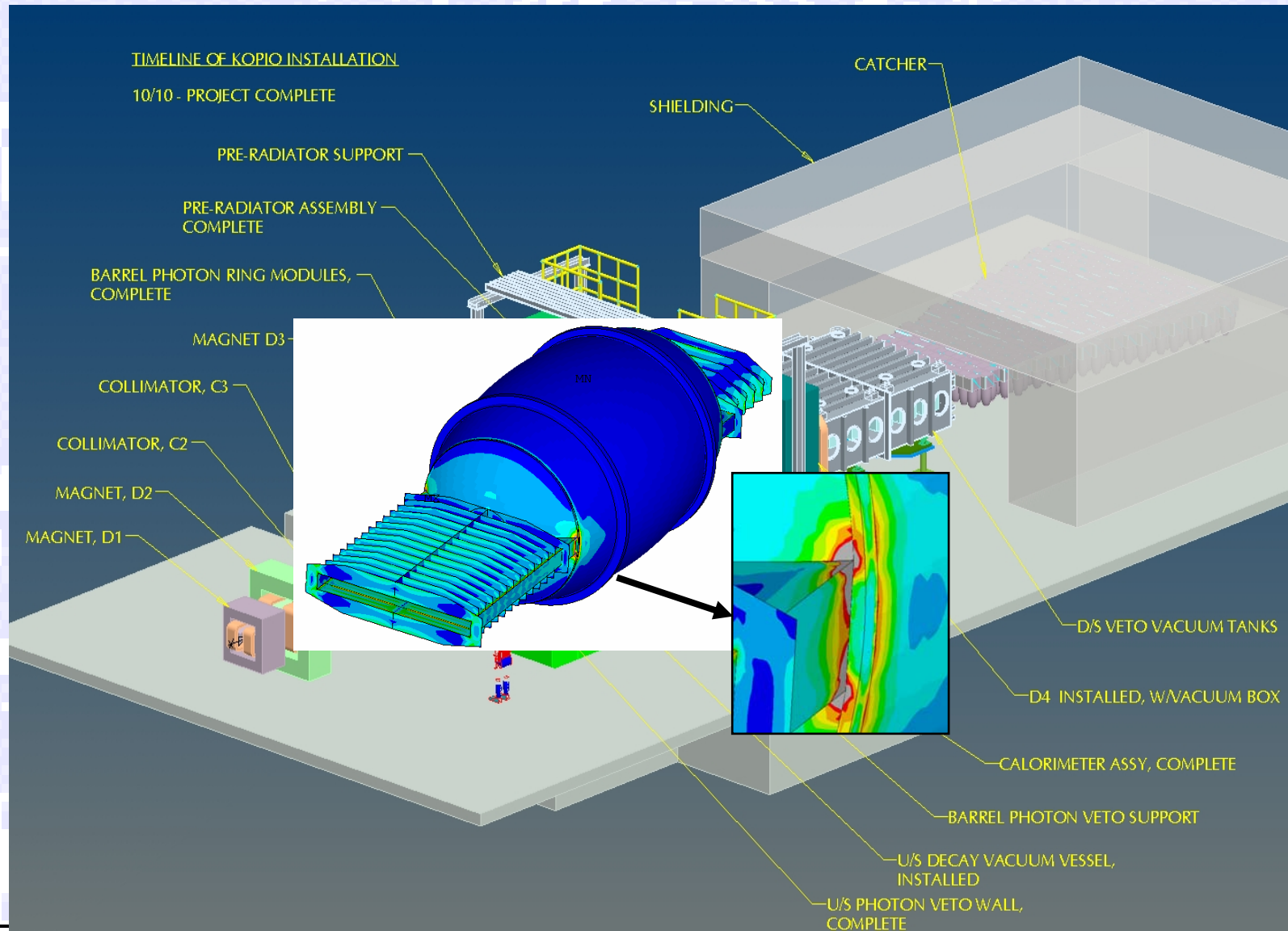
- JPARC approach emphasizes high acceptance for the two decay photons while vetoing everything else:

A hermetic “bottle” approach.

- The original KOPIO concept measures the kaon momentum and photon direction...Good! But costs detector acceptance and requires a large beam to compensate in flux.



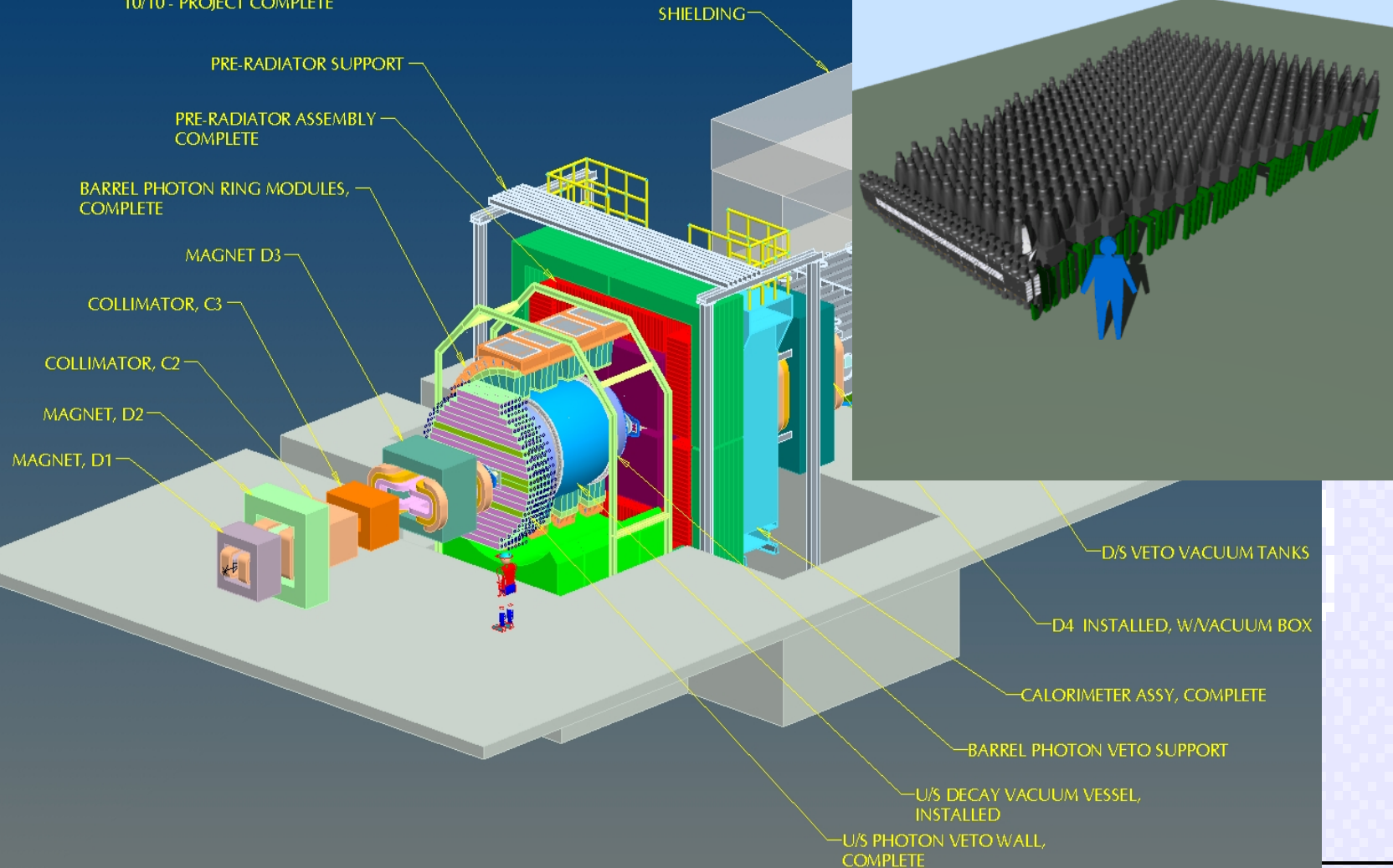
# Challenges of the KOPIO Design



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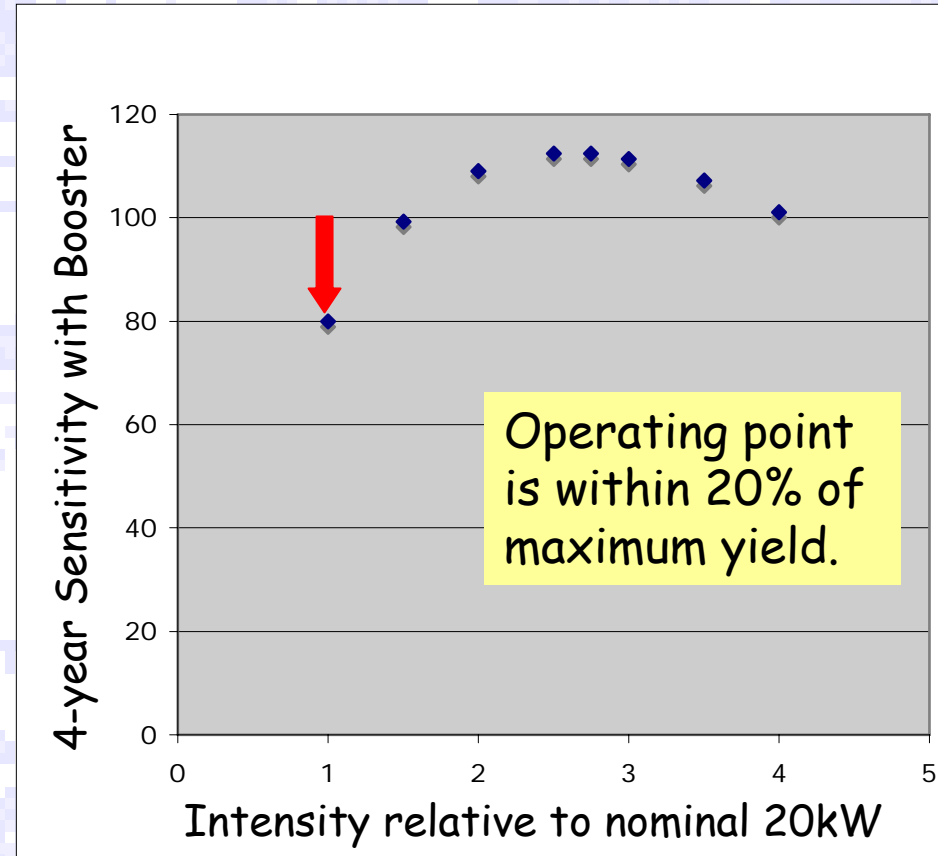
## TIMELINE OF KOPIO INSTALLATION

10/10 - PROJECT COMPLETE



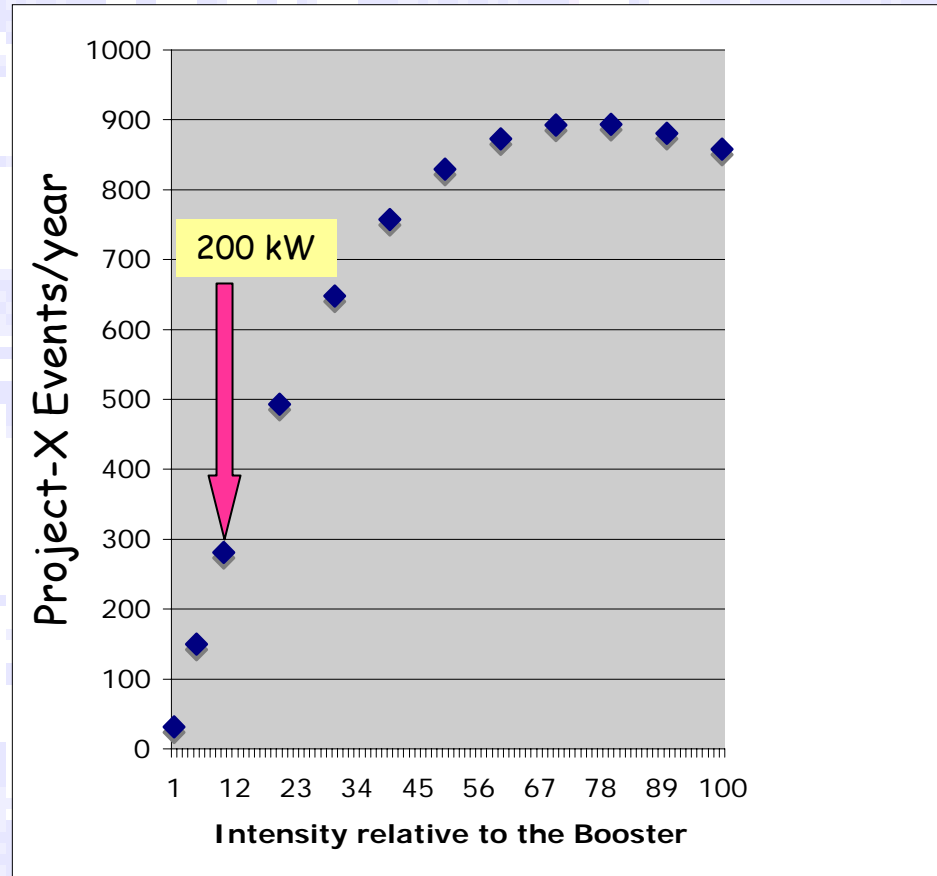
# Intensity Dependence of the KOPIO Design

- The KOPIO design is instantaneous rate-limited, primarily due to the large aperture of the neutral beam.
- The sensitivity could be increased by improved detector resolutions.
- **But** the KOPIO design is already not a cheap experiment, large area of detectors, many constraints.
- Could the potentially huge intensity increases of Project-X qualitatively change the picture?



# Improved Rate Performance of a "Pencil Beam" TOF Experiment.

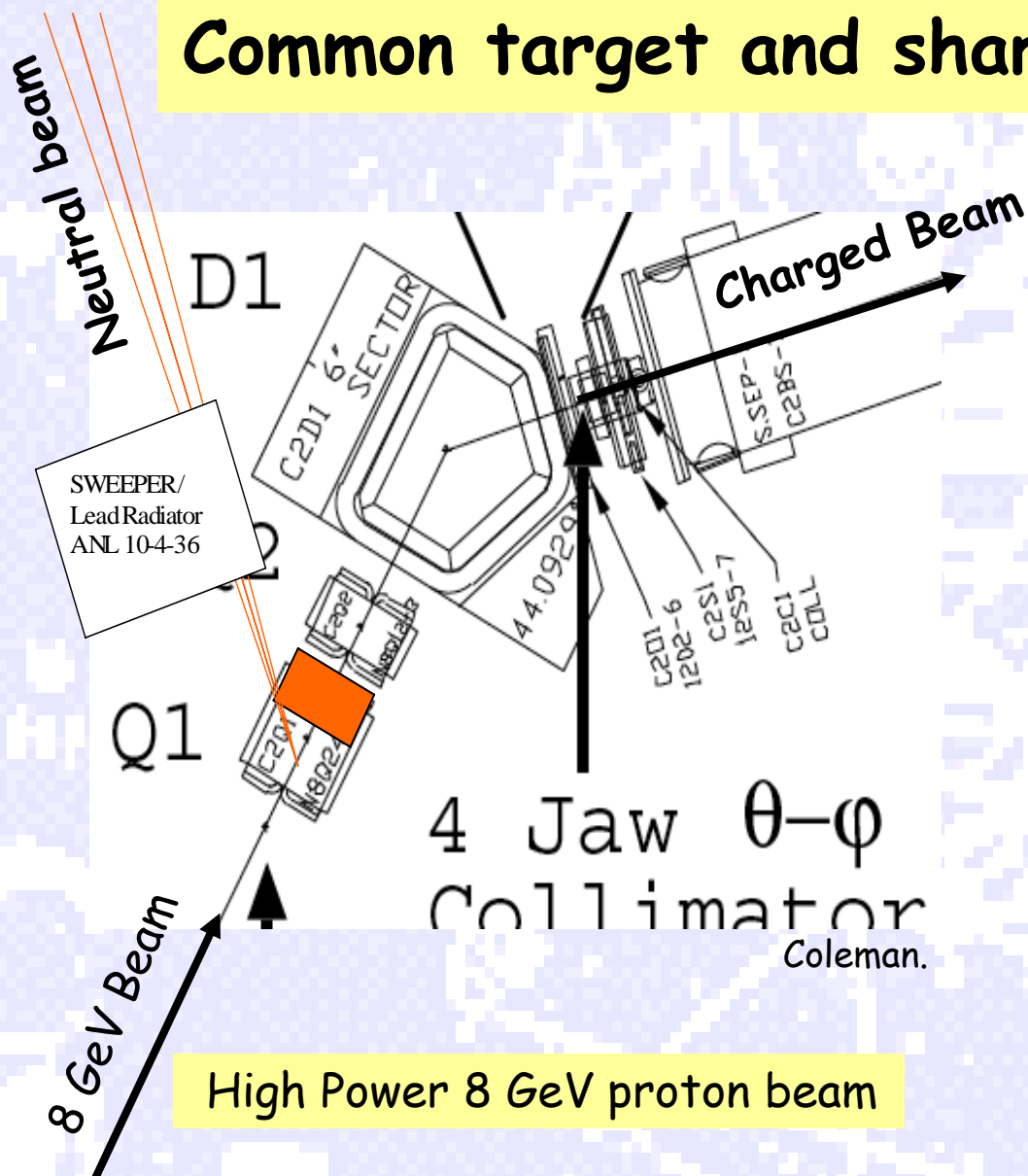
- Booster Power (20 kW):  
**30 equivalent events per year**
- Project-X (200 kW):  
**300 equivalent events per year**
- 200 kW operating point has robust rate performance which can be scaled to much higher beam power.
- Experiment designed with a pencil beam has substantially lower technical risk and likely lower cost.



# Neutral Mode, Where Fermilab and Project-X Could go...

- The very high 8-GeV proton flux from Project-X permits an evolution of the KOPIO detector concept with a small solid angle “pencil” neutral kaon beam which recovers the hermetic bottle veto coverage, increases the detector acceptance, and **reduces risk**.
- Such an experiment can start at the Booster with sensitivity of about 20-30 Standard Model events per year. This detector can be designed with Project-X in mind, which would follow with a precision measurement of about 300 events/year.
- A next-generation TOF-based experiment has a solid basis for design and costing.

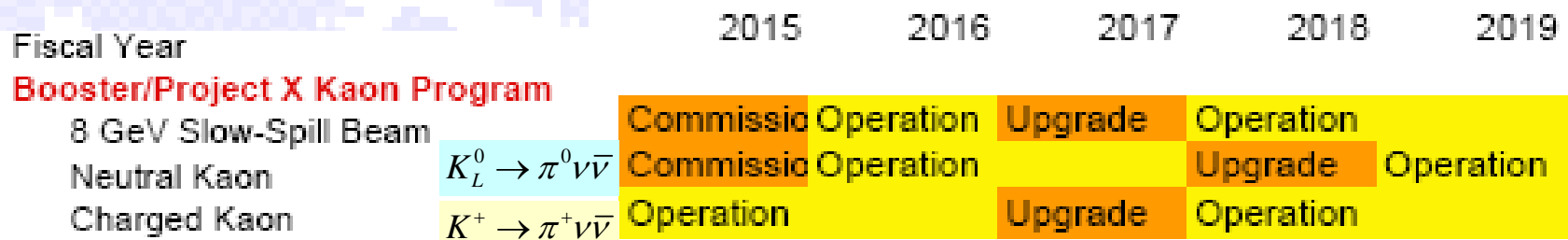
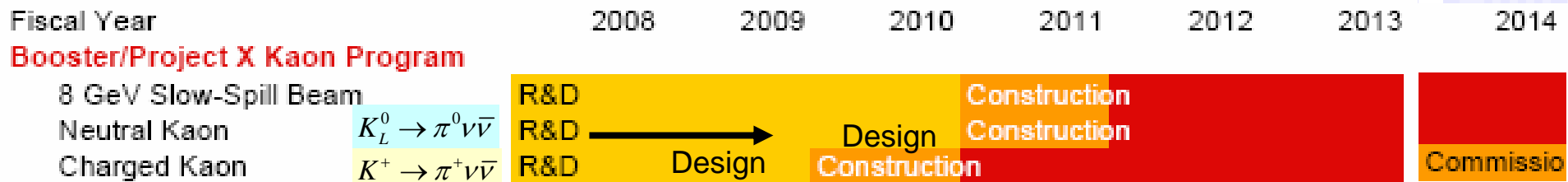
# 8 GeV Facility Vision: Common target and shared infrastructure.



- The large targeting angle required for the low energy neutral beam allows consideration of a simultaneous charged forward beam!
- First look at the layout is encouraging.
- **Big payoff** in beam and infrastructure economy.

High Power 8 GeV proton beam

# Kaon Experiments Staging Concepts



# The Disney Summary Slide...

- There was work at both Workshops!
- The Physics case for 1000-event  $K \rightarrow \pi \nu \nu$  experiments is stronger than ever, particularly with the conundrum of Minimum Flavor Violation.
- These are classic measurements which will stand the test of time. Many direct and associated compelling physics measurements exist at each step to the 1000-event goal.
- Concepts for 1000-event experiments have been developed and appear plausible. It didn't have to come out this way.
- Interesting facility concepts are beginning to emerge.
- Many opportunities for collaboration here.

# Realities...

- The timescale for Project-X will be long at best. Experiments driven by 8-GeV beam will have correspondingly long timescales to reach 1000-event sensitivity.
- In the interim there will likely be competition for beam power.
- No experimental facility or local collaboration at Fermilab now to build from.
- Facilities: \$50M. Neutral Expt: \$60M, Charged Expt: \$40M, (FY08).
- In limited funding scenarios progress will be slow.  
**Will it be sub-critical??**

# The Path Forward

- The lesson of rare-decays is that success requires a campaign. This was true for KTeV, the BNL program, and is now true for the European and Japanese programs.

Minimal buy-in from the Laboratory to initiate a campaign:

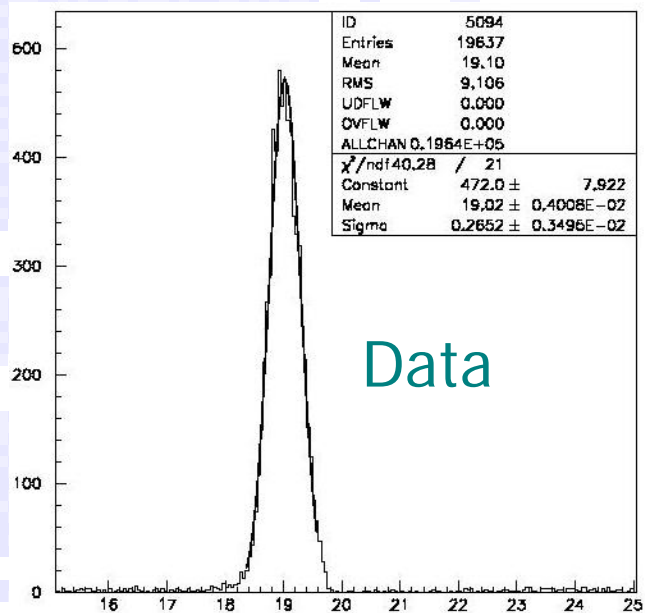
- Design effort on **infrastructure** for an experimental facility that can be driven by 8 GeV beam power as it evolves at the laboratory.  
Specifically: Buildings, beamlines, target, and beam conditioning.
- Support collaboration with the European and Japanese programs to create an environment for future investments at Fermilab.

# Spare Slides

# AGS Test Beam Results: Microbunch Width

## Data

93 MHz cavity at 22 kV  
gave  $\sigma = 240$  ps.

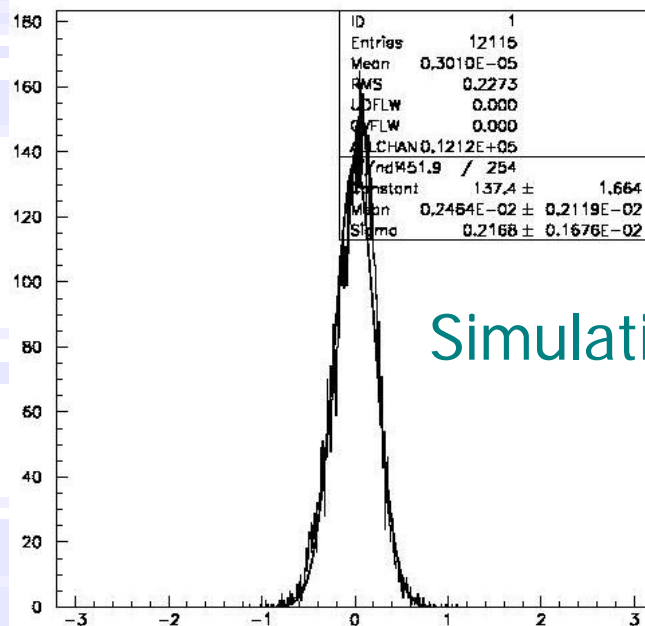


Data

Microbunch time, in ns

## Simulation

93 MHz cavity at 22 kV  
gave  $\sigma = 217$  ps.



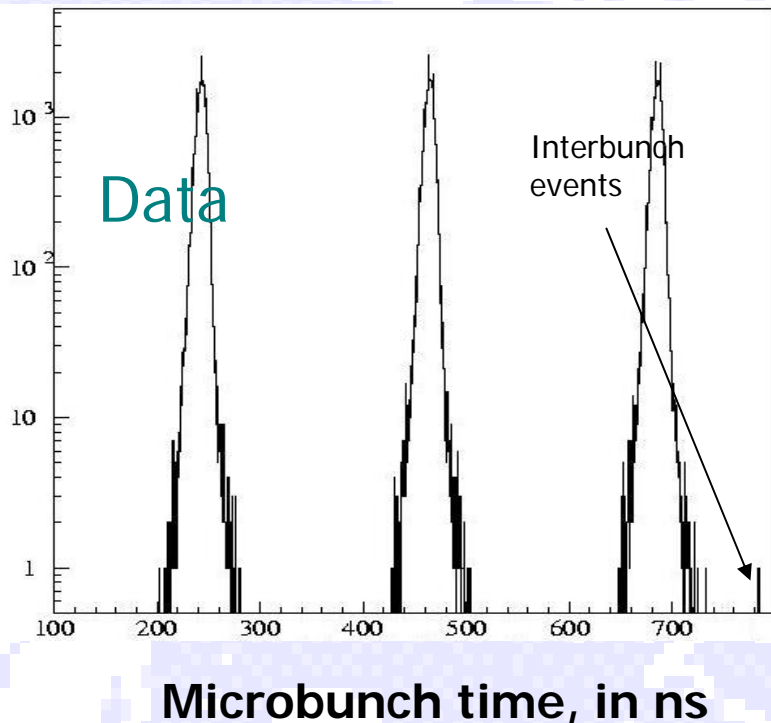
Simulation

Microbunch time, in ns

# AGS Test Beam Results: Interbunch Extinction

## Data

4.5 MHz cavity at 130 kV  
gave  $\epsilon = 8 (+/- 6) \times 10^{-6}$



## Simulation

4.5 MHz cavity at 130 kV  
gave  $\epsilon = 1.7 (+/- 0.9) \times 10^{-3}$

